REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	4/28/95	Final - 3/1/93 - 2/28/95

4. TITLE AND SUBTITLE
Non-Smooth Optimization Algorithms and Software Tools

5. FUNDING NUMBERS
F49620-93-1-0165
2304/CS
61102F

6. AUTHOR(S)
Elijah Polak
Professor and Principal Investigator

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of California, Berkeley
Electronics Research Laboratory
263 Cory Hall
Berkeley, CA 94720

8. PERFORMING ORGANIZATION REPORT NUMBER
442427-22525
AFOSR-TR- 95 - 0384

9. SPNSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NM
110 Duncan Avenue, Suite B115
Bolling AFB DC 20332-001

10. SPONSORING /MONITORING AGENCY

11. SUPPLEMENTARY NOTES
N/A

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release
Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
The broad research objective of this project was the development of optimization algorithms and related system-theoretic aspects for the integrated design of flexible structures and their control systems, and shape design.

14. SUBJECT TERMS	15. NUMBER OF PAGES	16. PRICE CODE
optimization, optimal shape design algorithms	3	

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unclassified	unclassified	unclassified	SAR

F49620-93-1-0165

NONSMOOTH OPTIMIZATION ALGORITHMS, SYSTEM THEORY, AND SOFTWARE TOOLS

FOR OPTIMAL CONTROL OF FLEXIBLE STRUCTURES, INTEGRATED DESIGN OF FLEXIBLE STRUCTURES AND THEIR CONTROL SYSTEMS, AND SHAPE OPTIMIZATION

E. Polak
Department of Electrical Engineering and Computer Sciences
and the Electronics Research Laboratory
University of California,
Berkeley, Calif. 94720

510-642-2644

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Unannounced	☐
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Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

April 25, 1995

Final Report for the Period 3/1/93 - 2/28/95

Prepared for

DEPARTMENT OF THE AIR FORCE
Air Force Office of Scientific Research
Bolling Air Force Base, DC 20332-6448

RESEARCH OBJECTIVES

The broad research objective of this project was the development of optimization algorithms and related system-theoretic aspects for the integrated design of flexible structures and their control systems, and shape design. The specific aspects under consideration are *(i)* efficient, consistent discretization techniques for use in semi-infinite optimization, optimal control, and optimal shape design algorithms that solve problems with dynamics governed by partial differential equations, *(ii)* global techniques for finding design parameters satisfying specifications, *(iii)* optimal control algorithms for discrete and distributed systems with control, state and shape constraints.

ACCOMPLISHMENTS

With AFOSR support, T. Baker, J. Higgins, Y-P Harn, J. Wiest, and C. Kirjner-Neto have carried out research under my supervision that has resulted in the award of PhD degrees. C. Kirjner Neto has been awarded the Departmental David Sakrison prize for best PhD dissertation of the year. A 600+ page, book [26] has been completed, containing many original results in semi-infinite programming and optimal control. In particular, the book will be unique in the literature dealing not only with nonlinear programming algorithms, but also with implementable versions of semi-infinite optimization and optimal control algorithms with control and state space constraints. An important highlight of our research is a theory of consistent approximations for use in the solution of semi-infinite optimization, optimal control algorithms, and shape optimization problems which makes it possible to construct algorithms for the solution of these problems using nonlinear programming libraries as subroutines.

Over the years, our research has dealt with *(i)* efficient, consistent discretization techniques for use in semi-infinite optimization, optimal control and shape optimization, *(ii)* discretization techniques with guaranteed minimum rate of convergence properties, *(ii)* optimal control algorithms that solve problems with dynamics governed by partial differential equations, *(iii)* various techniques for finding design parameters satisfying specifications, *(iv)* algorithms for moving horizon control of dynamical systems, and *(v)* algorithms for structural optimization and control. The results of this research were presented in the papers listed below.

PUBLICATIONS

[1] E. Polak, D. Q. Mayne and J. Higgins, "A Superlinearly Convergent Algorithm for Min-Max Problems", *JOTA* Vol. 69, No.3, pp 407-439, 1991.

[2] Y-P. Harn and E. Polak, "Proportional-Plus-Multiintegral Stabilizing Compensators for a Class of MIMO Feedback Systems with Infinite-Dimensional Plants", *IEEE Trans. on Auto. Contr.*, Vol. 36, No. 2, pp. 207-213, 1991.

[3] E. Polak and L. He, "A Unified Phase I Phase II Method of Feasible Directions for Semi-infinite Optimization", *JOTA*, Vol. 69, No.1, pp 83-107, 1991.

[4] J. Higgins and E. Polak, "An ε-active Barrier Function Method for Solving Minimax Problems", *JAMO*, Vol. 23, pp 275-297, 1991.

[5] E. J. Wiest and E. Polak, "On the Rate of Convergence of Two Minimax Algorithms", *JOTA* Vol. 71 No.1, pp 1-30, OCT 1991.

[6] E. Polak and L. He, "Finite-Termination Schemes for Solving Semi-Infinite Satisfycing Problems", *JOTA*, Vol. 70, No. 3, pp 429-466, 1991.

[7] L. He and E. Polak, "Multistart Method with Estimation Scheme for Global Satisfycing Problems", *Proc. European Control Conference*, Grenoble, July 2-5, 1991.

[8] C. Kirjner Neto and E. Polak, "A Secant Method Based on Cubic Interpolation for Solving One Dimensional Optimization Problems", *University of California, Berkeley, Electronics Research Laboratory* Memo No. UCB/ERL M91/91, 15 October 1991.

[9] E. Polak, J. Higgins and D. Q. Mayne, "A Barrier Function Method for Minimax Problems", *Math.Progr.*, Vol. 54, No.2, pp. 155-176, 1992.

[10] E. Polak, D. Q. Mayne, and J. Higgins, "On the Extension of Newton's Method to Semi-Infinite Minimax Problems", *SIAM J. Contr. and Optim.*, Vol. 30, No.2, pp. 376-389, 1992.

[11] E. Polak and L. He, "Rate Preserving Discretization Strategies for Semi-infinite Programming and Optimal Control", *SIAM J. Control*, Vol. 30, No. 3, pp 548-572, 1992

[12] E. J. Wiest and E. Polak, "A Generalized Quadratic Programming-Based Phase I Phase II Method for Inequality Constrained Optimization", *J. Appl. Math and Optim*, Vol. 26, pp 223-252, 1992.

[13] T. H. Yang and E. Polak, "Moving Horizon Control of Nonlinear Systems with Input Saturation, Disturbances, and Plant Uncertainty", *IJC* Vol. 58. No.4, pp. 875-903, 1993.

[14] E. Polak and T. H. Yang, "Moving Horizon Control of Linear Systems with Input Saturation, and Plant Uncertainty, Part 2. Disturbance Rejection and Tracking", *IJC*, Vol. 68, No. 3, pp. 639-663, 1993

[15] E. Polak and T. H. Yang, "Moving Horizon Control of Linear Systems with Input Saturation, and Plant Uncertainty, Part 1. Robustness", *IJC*, Vol. 68, No. 3, pp. 613-638, 1993

[16] E. Polak, "On the Use of Consistent Approximations in the Solution of Semi-Infinite Optimization and Optimal Control Problems", *Math Programing, Series B, Vol. 62, No.2, pp 385-414, 1993.*

[17] L. He and E. Polak, "Multistart Method with Estimation Scheme for Global Satisfycing Problems", *J. Global Optimization, No.3, pp 139-156, 1993.*

[18] E. Polak, T. Yang, and D. Q. Mayne, "A Method of Centers Based on Barrier Functions for Solving Optimal Control Problems with Continuum State and Control Constraints", *Siam J. Contr. Opt.*, Vol.31, pp 159-179, 1993.

[19] D. Q. Mayne and E. Polak, "Optimization Based Design and Control", plenary address, Proc. IFAC Congress, July 1993, Sydney, Australia.

[20] T. E. Baker and E. Polak, "On the Optimal Control of Systems Described by Evolution Equations", *SIAM J. Control and Optimization.* Vol. 32, No. 1, pp 224-260, 1994

[21] E. Polak, G. Meeker, K. Yamada and N. Kurata, "Evaluation of an Active Variable-Damping-Structure", *Earthquake Engineering and Structural Dynamics*, Vol. 23, pp 1259-1274, 1994.

[22] C. Kirjner Neto and E. Polak, "On the Use of Consistent Approximations for the Optimal Design of Beams, University of California Electronics Research Laboratory, Memo. No. UCB/ERL M94/22, 4/11/94.

[23] D. Q. Mayne, H. Michalska and E. Polak, "An Efficient Algorithm for Solving Semi-Infinite Inequality Problems with Box Constraints", *JAMO*, Vol. 30 No.2, pp. 135-157, 1994.

[24] A. Schwartz and E. Polak, "Consistent Approximations for Optimal Control Problems Based on Runge-Kutta Integration", *University of California, Berkeley, Electronics Research Laboratory* Memo No. UCB/ERL M94/21. *SIAM J. Contr. and Optim.*, in press.

[25] C. Kirjner-Neto, E. Polak, and A. Der Kiureghian, "Algorithms for Reliability-Based Optimal Design", Proc. *IFIP Working Group 7.5 Working Conference on Reliability and Optimization of Structural Systems*, Assisi (Perugia), Sept 7-9, 1994.

[26] E. Polak, *Computational Methods in Optimization: A Unified Approach, Second Edition*, Academic Press, 1996.